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OVERVIEW OF STRUCTURES RESEARCH

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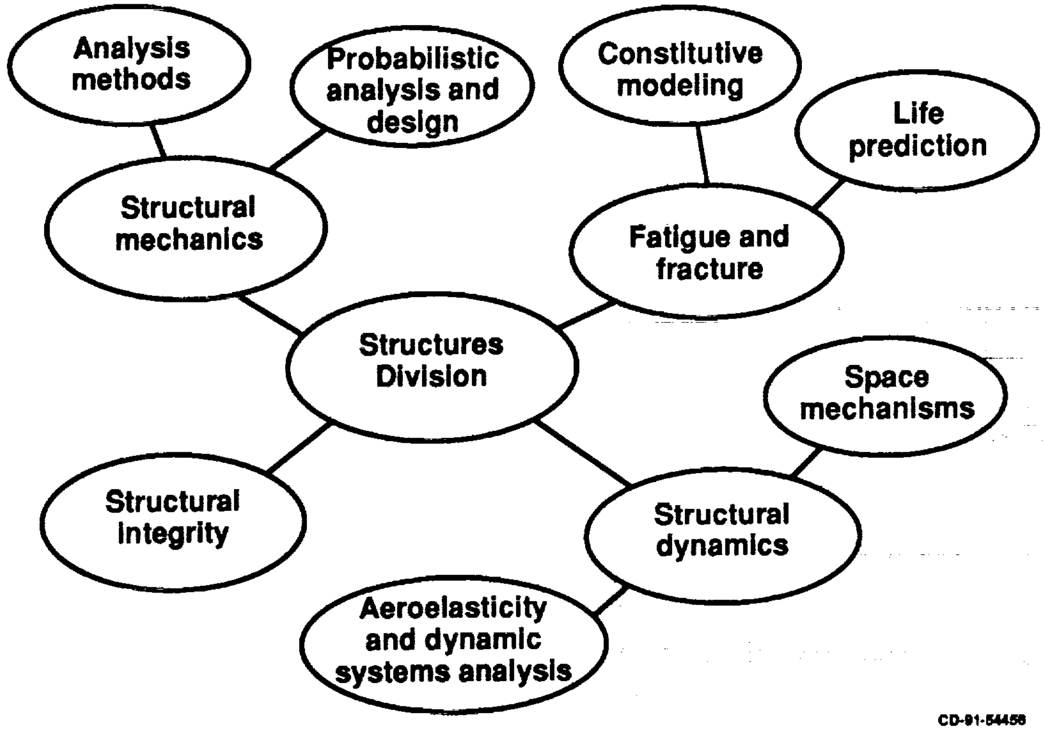
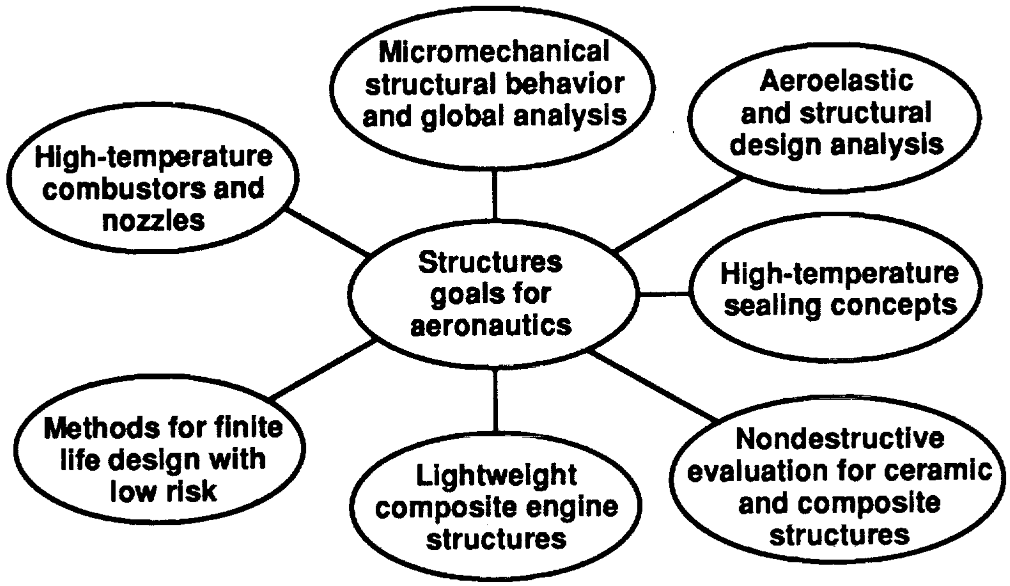
The development of aeronautical and space propulsion systems structures technology is the mission of the Structures Division. The technology required to achieve reliable, high-performance, lightweight structures needed for aerospace propulsion is among the most complex and challenging facing the design engineer. The division staff performs both fundamental and applied research in structural mechanics, fatigue and fracture, structural dynamics, and structural integrity. Research programs include probabilistic analysis and design, nonlinear material properties, symbolic logic, composite micromechanics, aeroelasticity, fatigue and fracture of composite structures, life prediction, and aspects of nondestructive evaluation. These programs, which for the most part are analytically based, are experimentally verified and are used to develop computer codes necessary for the design of complex engine structures. An overview of some of these programs is presented herein.

Structures Organization and Goals in Aeronautics



The Structures Division supports and performs research in both space and aeronautical propulsion systems. With turbomachinery, large rotational kinetic energies can couple with vibration modes and result in large vibrations or dynamic instabilities. Prediction and control of these instabilities are major thrusts of our research. Metal matrix composites, ceramics, and ceramic matrix composites (CMC's) offer significant potential for higher thrust-to-weight ratios for gas turbine engines. This can be accomplished by allowing higher cyclic temperatures with the use of both metallic and refractory high specific strength material systems. These materials are especially of interest for 3000 °F combustors and nozzles. Emerging nondestructive

Structures Organization and Goals in Aeronautics (continued)



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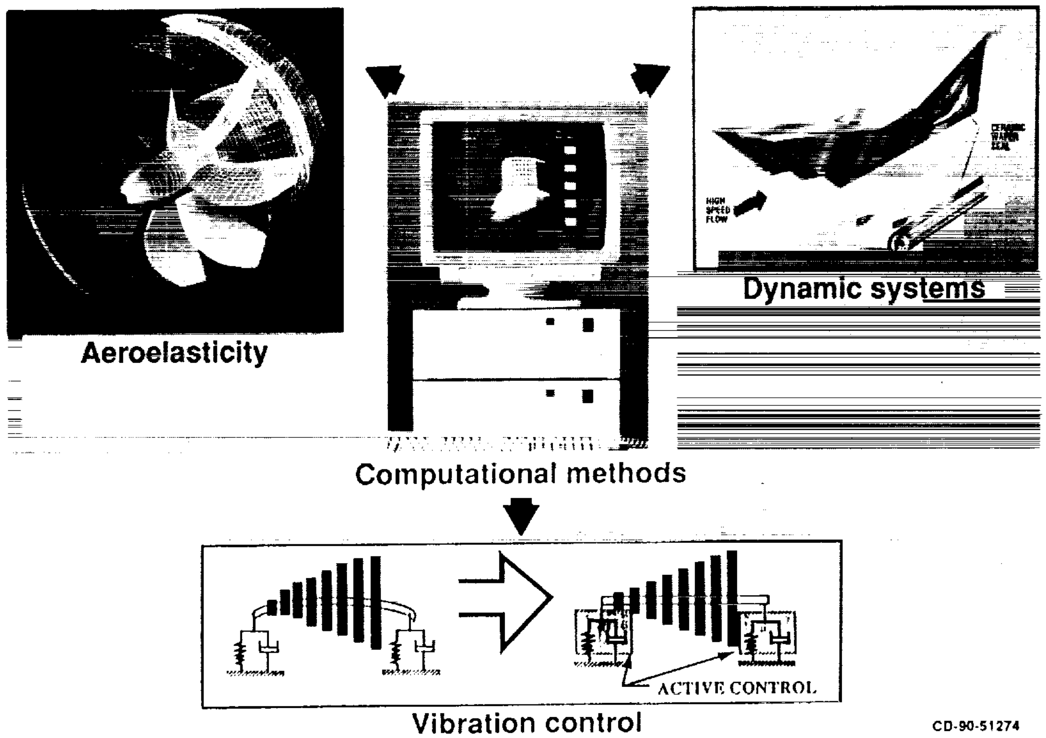
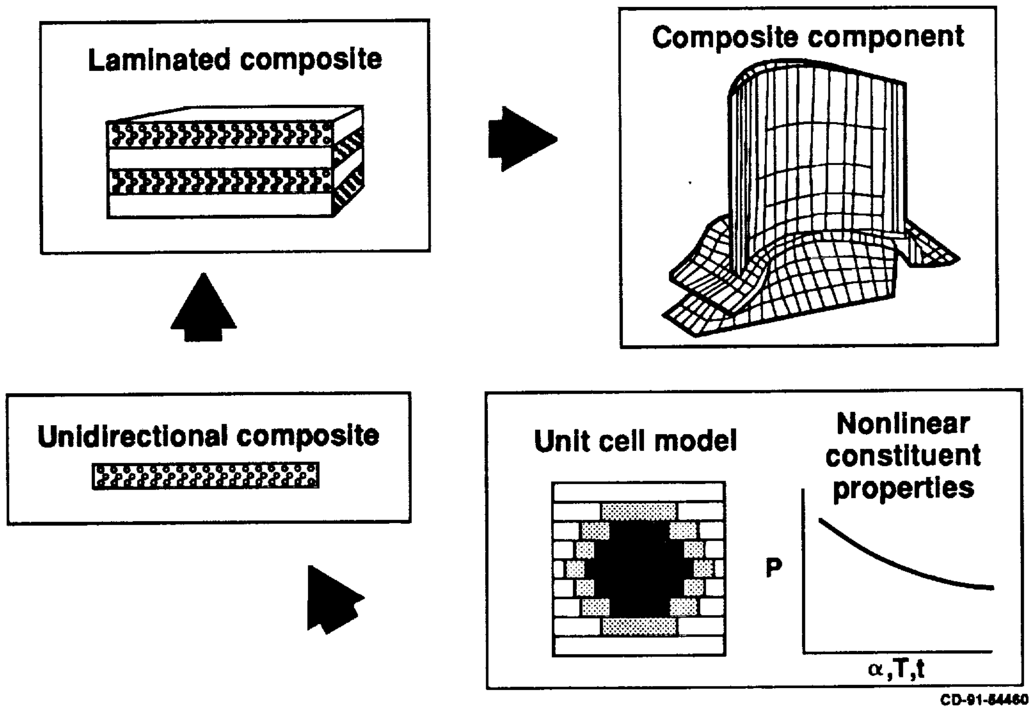
evaluation (NDE) techniques may be used to verify the mechanical properties of these materials and to assess their degradation in service. Our approach is to develop what we term "analytical NDE" for characterizing materials factors that govern mechanical properties. We study micromechanical structural behavior. We have focused our activities on viscoplastic constitutive model development, experiments to calibrate and validate the models, and the development of nonlinear structural analysis methods and codes. The codes are used to predict the global behavior of the engine structure. Pioneering research is being performed in probabilistic methodology to predict structure performance, life, and reliability. This approach to analysis not only provides probable variations in the response but also the probability of occurrence. The probabilistic approach, in conjunction with finite-element analysis, couples laboratory coupon data with methods to design for finite life with low risk. The severe thermal environments under which hypersonic aircraft, such as the National Aerospace Plane (NASP), will operate require cooling and sealing of the engine walls, especially the combustor. Work is being undertaken in unconventional high-temperature sealing technologies.

Aeropropulsion Structural Dynamics



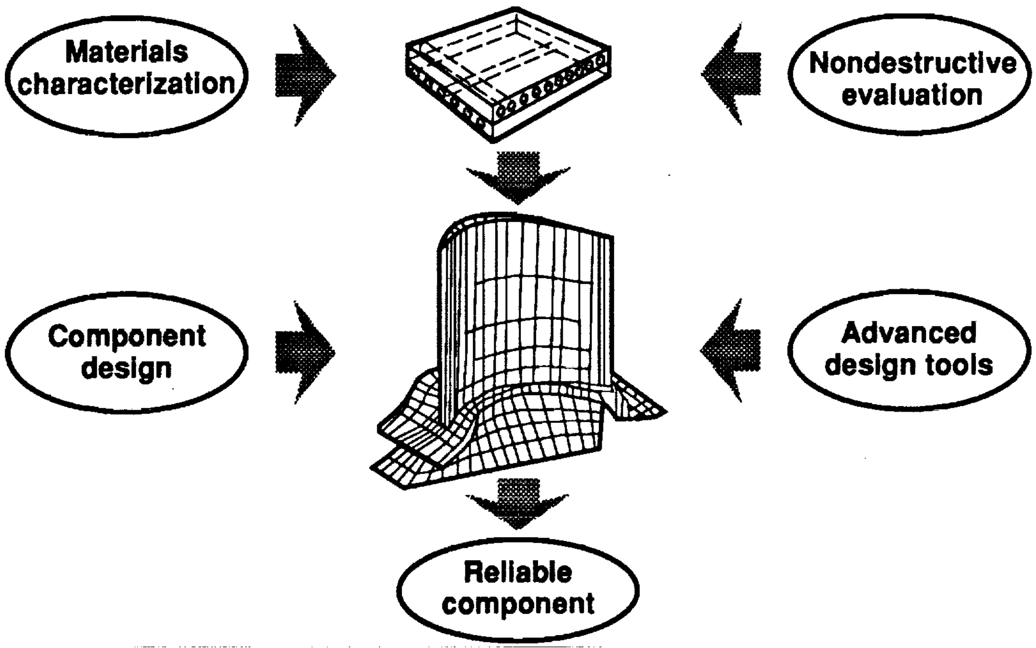
It is important to understand and define the physical interactions between thermal effects on basic material properties, the coupled aerostructural response (such as turbine blades made from such materials), and the coupling of the blade vibrations with net rotor-shaft rotor response. It is difficult, but not impossible, to simulate numerically these fundamental aeroelastic processes. In aeroelasticity, we are using both analytical and experimental means to define the performance limits of advanced propulsion systems, such as the ultra-high-bypass ducted fan engine shown here, and the supersonic fan, among others. Vibration control research is underway to develop and evaluate active control techniques and the required high-speed electronic controls to minimize unwanted shaft vibrations of both turbine engines and space turbopumps. Parallel computer processing is being used. The multigrid method, although used for years in fluid dynamics, now offers a new approach to nonlinear structural dynamics.

Composite Structures Simulation Relates Local Effects to Global Response



Mechanical performance and structural integrity of high-temperature metal matrix and ceramic materials is governed by local behavior at the level of the composite constituents, i.e., fiber and matrix. Hence, in the analysis and design of aircraft engine components which are ultimately to be fabricated from these composite materials, it is necessary to understand the local behavior of the material over the component volume and relate its effects to global structural performance. The critical local behavior is governed by such factors as imperfect bonding at the fiber-matrix interface, the progressive nature of microcracking, and nonlinear dependencies of constituent properties over the range of conditions in which the engine operates. We integrate constituent material models, cumulative damage models, composite mechanics, and global finite-element structural analysis (as depicted in the figure) to analyze this problem. With this capability, local effects on overall component behavior can be resolved and yet adequate efficiency achieved to be practical for realistic engine component applications.

Transition-to-Practice Technologies for Brittle Materials



- **Materials characterization and advanced design tools are being used to develop ceramic components with high reliabilities.**

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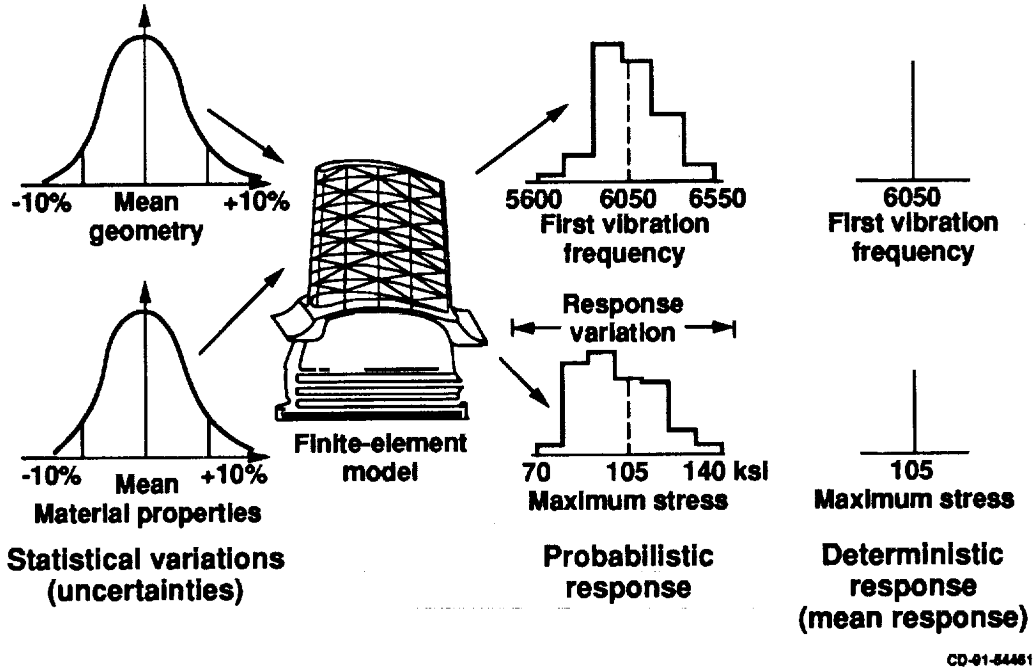
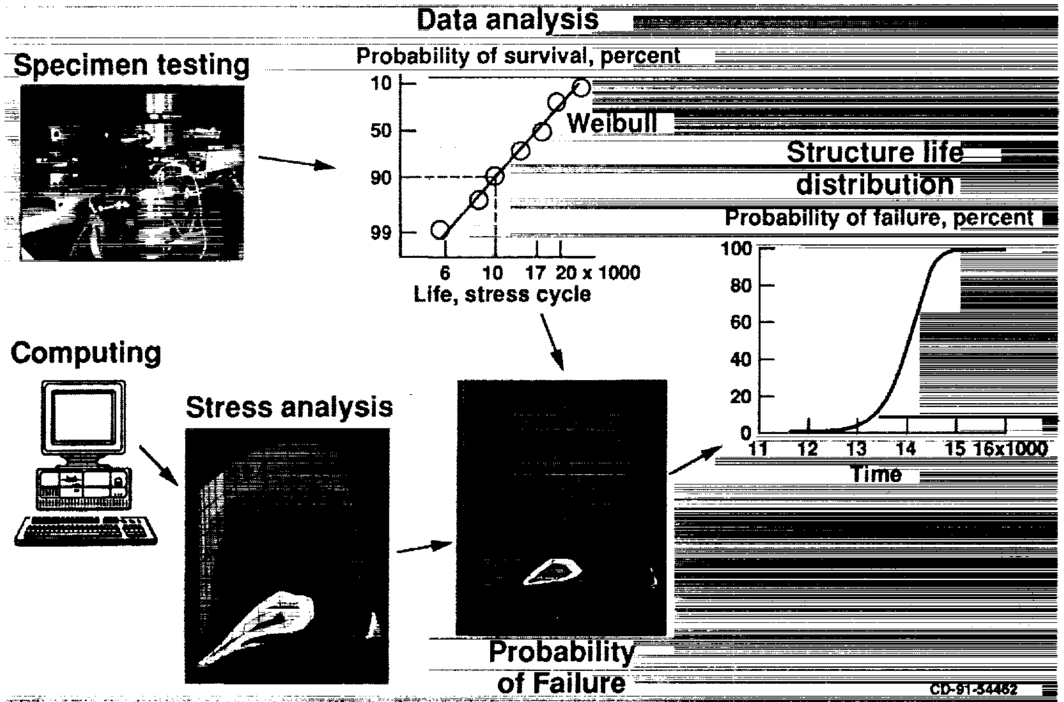
Transition-to-practice technologies are needed to bring brittle ceramic composite technology to the level necessary for practical application as aerospace materials. Two key areas where technologies are being used to develop ceramic composites are materials characterization and component design. Materials characterization techniques, both destructive and nondestructive, yield information on the material's failure mechanisms, integrity, and degradation. This crucial information guides and enhances the development of ceramic composites. Advanced design tools are also being developed to assist component designers with structural ceramic composite component development. These tools strongly influence the design of structural ceramic composite components by determining the component's reliability and life expectancy.

Probabilistic Analysis Methods Provide Decision-Making Basis for Structure Design



In-house studies have demonstrated that probabilistic analysis methods under random loading are more reliable than deterministic approaches. Probabilistic methods have been used predominantly in fatigue, fracture mechanics, and structural reliability analyses under random vibrations. We have been developing probabilistic methods which synthesize statistical variations in loading, component geometry, material properties, and environmental conditions into a risk assessment for all levels of response. Contrarily, the deterministic approach provides either a mean or median value and does not cover any probable variations. As a result, even after using a safety factor, the risk may or may not be within acceptable limits. These analyses can be used for process quality control, inspection interval, maintenance schedule, qualification testing, and certification thrusts.

Life Prediction Methods Bridge Gap Between Specimen Testing and Full-Scale Engine Structure



Using probabilistic methodology, the component design survivability can be mapped by incorporating finite-element analysis and probabilistic material properties. The method evaluates design parameters through direct comparisons of component survivability expressed in terms of Weibull parameters. The method allows the use of statistical data obtained from laboratory coupon testing under environmental conditions to be integrated into life and risk analysis of full-scale engine structures. It is possible through an interactive design process to minimize the risk of failure for a given operating time or, conversely, to design for a finite life for a defined risk. When Weibull parameters and the stress-life exponent of the material are unknown, it is permissible to assume these values in order to obtain a qualitative, if not quantitative, evaluation of a structural design. We are currently applying these methods to full-scale structures such as turbine blades and disks where full-scale component data exist.

CONCLUDING REMARKS

The development of aeronautical propulsion systems structures technology required for high-performance, advanced aircraft has been the mission of the Structures Division for many years. We carry out both fundamental and applied research in pursuit of this mission. We work cooperatively with industry and academia to apply the fundamental disciplines found in the university with the design and application needs of industry. It is from this perspective that the presentations were prepared.